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Lyons, Anthony P.

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The Pennsylvania State University, Applied Research Laboratory, P. O. Box 30, State College, PA 16804-0030

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
Environmentally caused false alarms (FA) and false targets (FT) present some of the most difficult challenges for modern torpedo systems in systems in shallow water. In many cases, the mechanism for FA/FT is clear: scattering from exposed rock on the seafloor, e.g., rock outcrops and ridges. The long-term goals of this research program aim primarily to increase our understanding of and simulation capability for weapons-frequency acoustic scattering from rock outcrops. This knowledge will be used to develop methods for simulating FA/FT in areas of rock outcrops, for predicting where high FA/FT areas might occur and for predicting the influence of parameters such as slope or aspect on FA/FT levels. This effort will also allow the performance of sonar systems to be predicted for rocky environments, which will allow the negative impact of non-Rayleigh clutter on detection and classification to be minimized or robust signal processing methods to be developed or tested. Knowledge gained might also lead to methods for environmental assessment techniques for the characterization of rocky areas for example at test sites.

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rock outcrops, clutter, false alarms, seafloor scatter

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Contract Information

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Title of Research	Characterization and Simulation of False Alarms Caused By Rock Outcrops
Principal Investigator	Anthony P. Lyons
Organization	The Pennsylvania State University Applied Research Laboratory

Technical Section

Objectives

Long term goals:

Environmentally caused false alarms (FA) and false targets (FT) present some of the most difficult challenges for modern torpedo systems in shallow water. In many cases, the mechanism for FA/FT is clear: scattering from exposed rock on the seafloor, e.g., rock outcrops and ridges. The long-term goals of this research program aim primarily to increase our understanding of and simulation capability for weapons-frequency acoustic scattering from rock outcrops. This knowledge will be used to develop methods for simulating FA/FT in areas of rock outcrops, for predicting where high FA/FT areas might occur (which is of obvious tactical importance), and for predicting the influence of parameters such as slope or aspect on FA/FT levels. Of equal importance, is exploring and quantifying the relationship of the parameters of the K distribution, now being used for simulating clutter, to physical characteristics of rock outcrops. Once mechanisms are established, this cffort will also allow the performance of torpedo sonar systems to be predicted for rocky environments, which will allow the negative impact of non-Rayleigh clutter on dctection and classification to be minimized or robust signal processing methods to be developed or tested. Knowledge gained might also lead to methods for environmental assessment techniques for the characterization of rocky areas for example at test sites.

Objectives:

Several tests performed by Applied Research Laboratory - Penn State (ARL/PSU) over the last decade at the test ranges of SHOBA and Nanoose have confirmed that failures caused by false targets were in areas of exposed rock. Data collected as part of the ONR sponsored Multi-Mission Program at ARL has shown repeatable correlation of false detections with large-scale bathymetric features suggesting ridge-like structures as a cause. We propose to address the main causes of FA suggested in this initial work by examining co-located torpedo frequency acoustic data along with high-resolution ground truth.

Concisely the proposed objectives are:

1. Determine geological controls on rock outcrop induced FA/FT and the dependence of FA/FT on these environmental parameters.
2. Model the scattering and statistics of scattering for the FA/FT mechanism of rough rock ridges in a framework of recently developed physics-based clutter models.

3. Coordinate and collaborate with similar work being performed at NRL.

Approach

Statistical characterization:

The first component in the proposed work involved (1) examining the historical literature on the geo-acoustic characteristics of rock features (e.g. roughness, size distribution) and (2) analyzing existing acoustic and environmental data obtained by ARL/PSU during tests in areas of known rock outcrop caused FA/FT. With this information we characterized scattering from rock in terms of both mean levels and higher-order statistics. Data taken at different aspects to geological features were obtained to determine whether any dependence on slope or aspect existed. Data consisting of high-resolution sonar measurements were taken. Environmental data, such as surface roughness was collected as part of this project

Model development:

The second component of the proposed work was to cxamine the connections between the rock outcrop geo-acoustic parameters and the resultant reverberation statistics via physics-based models. A physical description of the environment was linked to weapons-frequency acoustic scattering statistics in the framework of physics-based models. This relationship allowed simulation of false alarms and false targets for scenarios for which experimental data do not exist. The physical dcscription of the environment was based on knowledge gained from the literature for rock outcrops and ground truth collected at the high FA/FT sites.

NRL experiments:

A third component, informed by work in the previous two, was to assess the validity of any developed models by working in conjunction with Scientists at the Naval Research Laboratory (NRL) on numerical models. NRL-DC scientists initiated a highly relevant and coordinated project on scattering from rock outcrops which will began last year. The proposed effort included collaboration with these NRL scientists to both inform them of any relevant results and to assess the validity of any developed models. We have worked in conjunction with Roger Gauss, Dave Calvo and Joe Fialkowski of NRL as they began and proceeded with their own numcrical studies. The PI and student involved in this research have spent time visiting with and sharing data with the NRL researchers as they have worked in their complementary project.

Progress

Work completed:

Over the course of the project, work was performed by graduate student Derek Olson and the PI on modeling scattering from rocky outcrops described in the first component listed in the technical approach described above. As virtually no information exists on scattering from rock outcrops, we have worked on obtaining relevant physical characteristics of rock outcrops, such as the roughness and morphology for use in models of acoustic scattering from rock. We compared numerical simulations to acoustic data that was collected using high-resolution acoustic data from a high-frequency imaging sonar. The sonar data analyzed this year was collected in April, 2011 during a joint field expcriment that took place near Larvik, Norway, as part of a collaborative work with the Norwegian Defence Research Establishment (FFI). The SAS system operated at a center frequency of 100 kHz, has a bandwidth of 30 kHz and was operated from the HUGIN Autonomous Underwater Vehicle (AUV). A sample SAS image of a rock outcrop in the experimental area obtained with FFI's SAS system and high-resolution bathymetry of the same area can be seen in Figure 1. From the Larvik, Norway, trial, scattering strength estimates were found to range from -5 dB to -35 dB over grazing angles of 0 to 90 degrees and yielded an approximate Lambert parameter of approximately -8 (very high). The measured scattering cross section from the leeward (or 'plucked') side exhibited variability on the order of 10 dB and probability of false alarm (PFA) curves were extremely non-Rayleigh with a 'knee' in the curves suggesting two scattering mechanisms were at work as will be discussed later in this report.

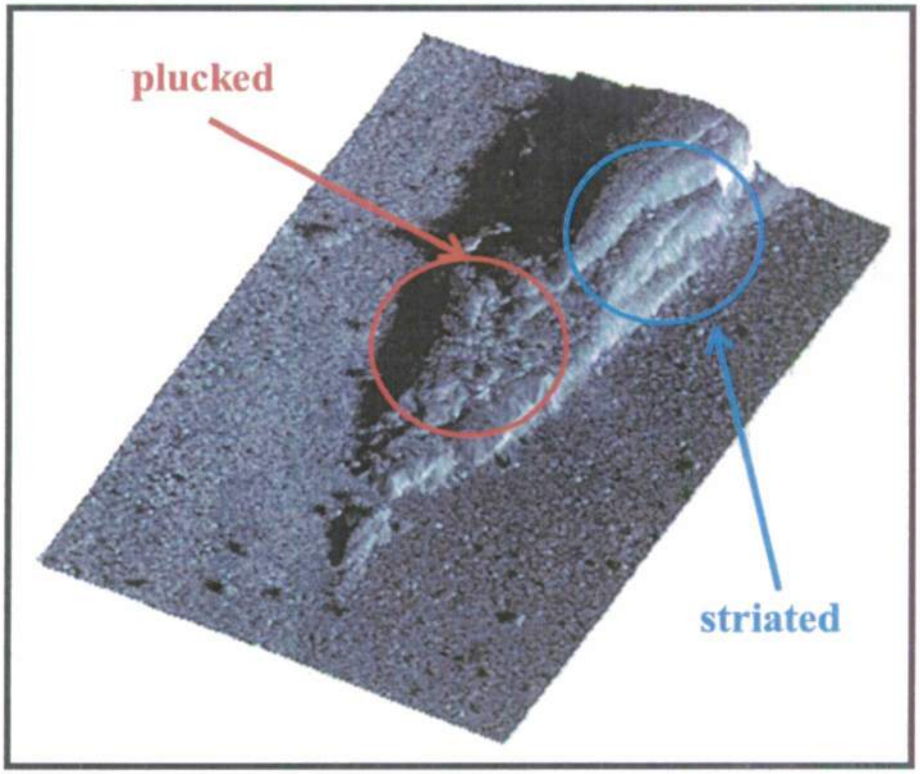

Figure 1. Example synthetic aperature sonar image and high-resolution bathymetry from the FFI system taken in the Oslofjord during a joint experiment near Larvik, Norway in April, 2011. The portion of the outcrop seen is this figure is approximately 5 m wide and 15 m in length, with the actual length being larger.

Because rough rock surfaces have a very large RMS height compared to the acoustic wavelengths used in sonar systems and do not conform to typical seafloor roughness models, such as the small-slope approximations (SSA), an approximate model that will predict the scattered field is currently not feasible. Scattering behavior for these surfaces is driven by near-specular scattering from step facets, non-local shadowing by neighboring facets, diffuse scattering from convex corners and edges, and multiple scattering from concave corners of the surface. Approximate models cannot capture scattering from these types of surface features and therefore are of little use as predictive models of the statistics of scattering. Given the inadequacy of approximate models we have investigated numerical models, specifically the boundary

element method (BEM) to address which of the scattering mechanisms listed above were primarily responsible for the non-Rayleigh scattering statistics.
Additionally, we began discussion and coordination with researchers at NRL on their related project, "Modeling of High-Frequency Broadband False Target Phenomena" (project PIs are Roger Gauss, Dave Calvo, and Joe Fialkowski). This collaborative work is continuing with exchange of data and ideas.

Sample Results:

From the Larvik, Norway, trial, scattering strength from rocks was extracted from the normalized pressure squared by selecting a region and averaging in cross-range, and then averaging over one degree increments. To measure the scattering strength from a rock surface, the mean slope was determined from high-resolution interferometric bathymetry so that the global grazing angle of the ideal mean seafloor could be mapped to the local grazing angle of the rock. After system calibration, scattering strengths were found to range from -5 dB to -35 dB over grazing angles of 0 to 90 degrees. The left plot in Fig. 2 displays sample scattering strength data taken from the rough ('plucked') portion of a granite rock outcrop.

Surfaces resulting from glacial quarrying are composed of steps whose orientations and size distributions reflect the internal fault organization of the bedrock. A mathematical model of the leeward side of an outcrop can be generated to use in numerical simulations of acoustic scattering. Random stepped profiles can be simulated by generating horizontal and vertical segments, each with their own size distribution, then connecting them together. This surface model's input parameters are functions of the distributions of both the vertical and horizontal segments, and their appropriate parameters. The exponential distribution has been shown to describe field measurements of block size distribution in bedrock.

The BEM solves the Helmholtz-Kirchhoff Integral Equation (HKIE) by discretizing the boundary of a surface, and converting the integral equation into a matrix equation. In this research the boundary and surface pressure were described by piece-wise continuous linear elements whose endpoints are the nodes of the surface. At each node, the pressure depends on the pressure integrated over all other elements. If the HKIE is formulated at each point, then a linear system of equations can be formulated, and solved for the pressure, or its normal derivative, at each node and element. The resultant surface pressure and its normal derivative are then propagated to field points within the homogeneous medium. From this pressure at a field point, scattering strength can be computed as well as PFA for various values of kh and kL (mean vertical and horizontal facet scales times the acoustic wavenumber). To estimate the PFA, a histogram of the pressure amplitude at each angle, normalized by its variance is formed. The histogram is normalized by its discrete integral, and then converted to CDF by taking the normalized cumulative sum. The right plot in Fig. 2 displays a set of BEM derived scattering strength curves for the facet surface model with varying kL and a fixed kh of 4. Predictions are close to the levels seen with in real data and are roughly Lambertian in shape, which was also seen in the real data. The left plot in Fig. 3 displays experimentally determined PFA for the same surfaces and is clearly non-Rayleigh. The PFAs exhibit a concave curvature in log-linear space (a 'knee'), which is not possible with the K-distribution and is suggestive of that the data may require a combination of mechanisms (or mixture model) to fit the curve. The two mechanisms contributing could be scattering from small scale roughness combined with specular scattering from facets oriented close to normal incidence to the sonar system. Diffraction from sharp edges may also contribute strong scattering that is non-directional as for scattering from small scale roughness. The large number of specular points provided by the large roughness causes a large number of high-amplitude events skewing the 'tail' of the distribution. A mixture model consisting of Rayleigh and K would be a good candidate to fit PFA from this two-component scattering surface.

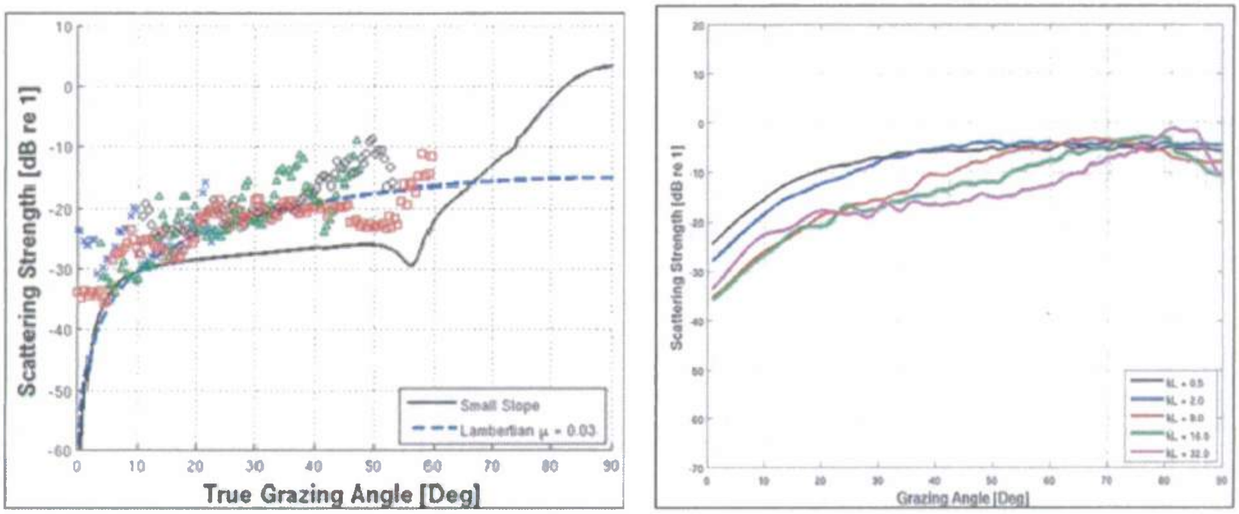

Figure 2. Scattering strength of rock outcrop at 100 kHz obtained from FFI's HUGIN HISAS imaging sonar (left) and estimates of scattering strength obtained from BEM simulations with a facet model used for the rough surface (right).

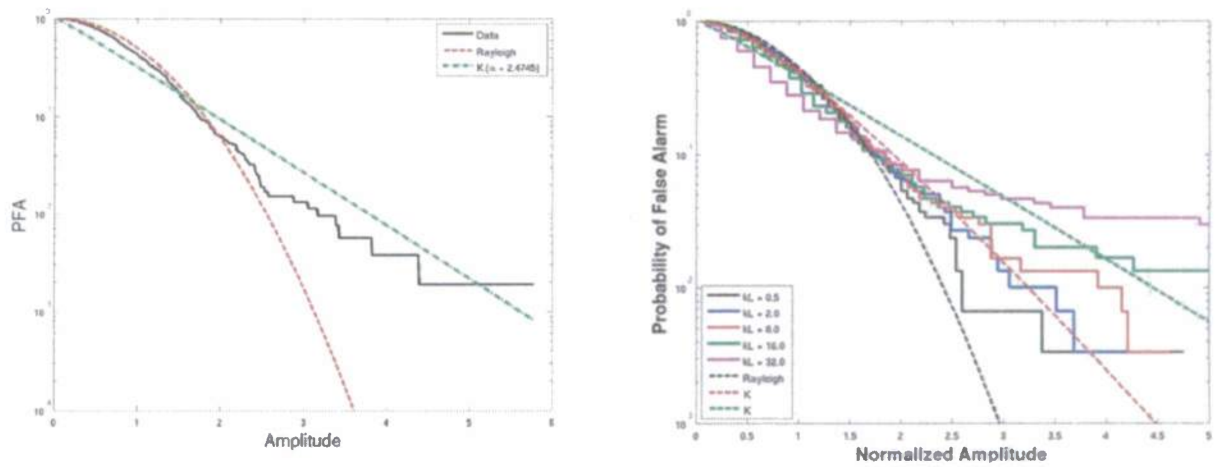

Figure 3. PFA of rock outcrop at 100 kHz obtained from FFI's HUGIN HISAS imaging sonar (left) and estimates of PFA obtained from BEM simulations with a facet model used for the rough surface (right).

Examination of the surface pressure distribution computed by the BEM can reveal clues to the dominant features responsible for the trends observed in the cross section and PFA curves. An examples of the surface pressure distribution for kh = 4.0 are displayed in Fig. 4. The incident pressure is directed from the upper left corner, towards the lower right corner at 45° (note that the vertical scale is exaggerated). In both plots, the facets facing towards the incoming wave have higher amplitude than facets pointing away. For certain facets, the maximum pressure amplitude is near the center of the facet, whereas for others, it is at the edge, near a corner. It is hypothesized that for facets with a maximum near the center, the dominant process is that of specular scattering from planar segments. For segments with the maximum near the corner, diffractions from the corner dominate. The determination of whether corner diffraction or specular scattering dominates a given facet is not clear, and may depend on its size, and relative position to other corners of the surface. Non-local occlusion may also be responsible for decreasing the amplitude of the surface pressure on a facet. True parameters for use in the surface model used in this research have been collected in a recent field experiment and are currently being analyzed. Figure 5 shows a sample of ground truth collected on the types of structures causing the scattering characteristics seen in Figs. 2 and 3. The left photo in figure shows one image of a stereo pair collected on the rough or 'plucked' side of a glacially formed rock outcrop. The right image is the height distribution calculated using both images in the stereo pair.

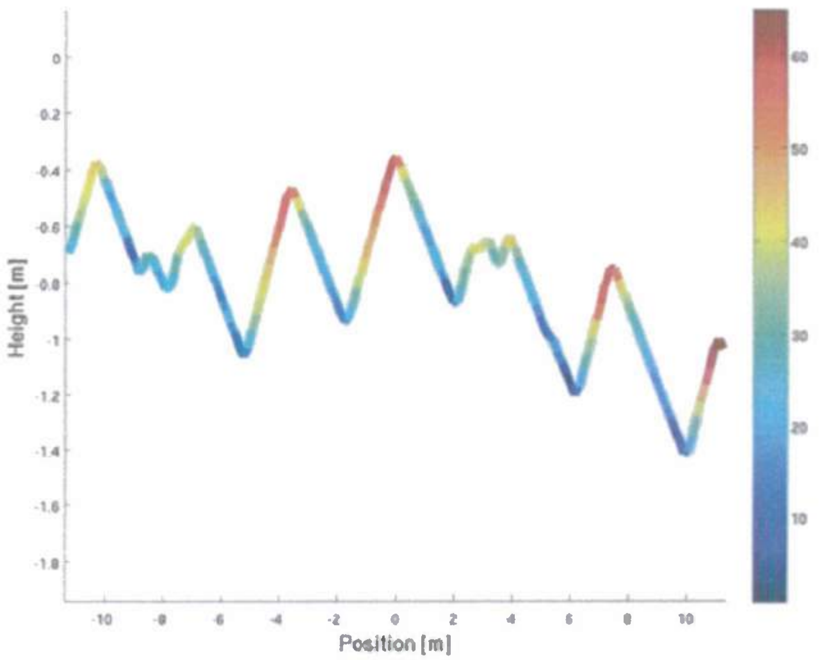

Figure 4. Example of the surface pressure distribution for kh = KL = 4.0.

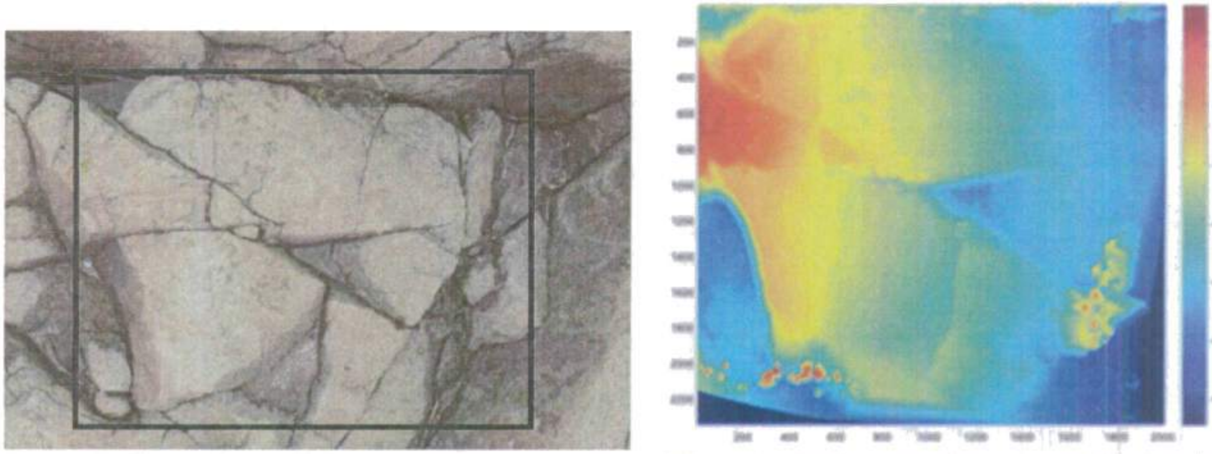

Figure 5. Example synthetic aperature sonar image (left) and scintillation index map of the Oslofjord near Larvik, Norway. Red areas are more cluttered and would have more false alarms.

Impact/applications:

The primary work completed over the course of this project consisted of developing techniques for modeling scattering from rough rock outcrop areas and comparing results with acoustic data sets collected from rocky areas. The proposed project was designed to increase our understanding of and simulation capability for weapons-frequency acoustic scattering from rock outcrops. This study resulted in useful knowledge of rock outcrops as a mechanism responsible for shallow water false alarms and how levels of false alarm relate to physical properties and features of the outcrops. Guidance relevant to this false alarm mechanism is being provided to researchers at the Naval Research Laboratory and will also be provided to those developing digital simulation content for the Guidance and Control (D&I) Modeling and Simulation TEAMS Initiative. Other deliverables are journal articles that are in preparation based on the conference presentations listed below.

Related Projects:

A related ONR project (Grant N00014-11-1-0546) is Numerical Studies on the Statistics of Acoustic Scattering from Rock Outcrops managed by Elroy S. Crocker, code 333.

Publications and technical presentations supported by this project:

Olson, D.R. and A.P. Lyons, 2011, 'Characterization and scattering measurements from rock seafloors using high-resolution synthetic aperture sonar,' The Journal of the Acoustical Society of America, 10/2011; 130(4):2349. DOI:10.1121/1.3654409.

Olson, D.R. and A.P. Lyons, 2011, Parameterization of rocky sea-floors using high-resolution synthetic aperture sonar, in Proceedings of 4th Underwater Acoustic Measurements Conference: Technologies and Results, Kos, Greece, eds. John S. Papadakis and Leif Bjorno.

Olson, D.R. and A.P. Lyons, 2013, Numerical simulation of acoustic scattering from very rough glacially-plucked surfaces using the boundary element method, in Proceedings of 5th Underwater Acoustic

Measurements Conference: Technologies and Results, Corfu, Greece, eds. John S. Papadakis and Leif Bjorno.